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Coastal reservoir-a technology to supply sufficient, high-quality and affordable water to industry with minimum environmental/social impact

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COASTAL RESERVOIR-A TECHNOLOGY TO SUPPLY SUFFICIENT, HIGH-QUALITY AND AFFORDABLE WATER TO INDUSTRY WITH MINIMUM ENVIRONMENTAL/SOCIAL IMPACT

Shu-Qing Yang[1]

ABSTRACT: This paper discusses how to supply sufficient water to meet industrial water demand. Australia is not running out of water, but water is running out of Australia's rivers. About 440km^3/year of runoff is lost to the sea, and the total water usage is only about 5-6% of the water availability. Australia is one of the most resourceful countries in the world. All industrial water for the coastal areas can be supplied from coastal reservoirs, even the high-quality cooling water for steel making. To supply sufficient water to inland areas, the author has suggested that the Murray-Darling basin's cotton farms should be relocated to downstream areas near its coastal reservoir, thus the agricultural water demand is fully met and also the environmental flow is increased significantly. Therefore, its existing dams can be used for mining industry. Water pipelines may be needed to pump water from these dams to the mining sites, trains can also transport water bags from ports to inland areas.

INTRODUCTION

Water scarcity has always been a contentious issue in Australia, the driest inhabited continent in the world where about 70% of its land is classified as arid or semi-arid. Australia's rainfall and runoff are the lowest when compared with other continents as shown in Table 1.

Table 1. Comparison of Australia and other continents' rainfall and runoff in Australia

Continent	Area (million km2)	Rainfall (mm)	Runoff		%Runoff
			mm	km^3	
Africa	30.3	690	260	7900	38
Asia	45	600	290	13000	48
Australia	7.7	465	57	440	12
Europe	9.8	640	250	2500	39
North America	20.7	660	340	6900	52
South America	17.8	1630	930	16700	57

The average annual rainfall over the whole country is 465 mm, with, 87% of this total rainfall lost through evapo-transpiration and only about 12% of the rainfall or 57 mm on average enters the streams, the remainder 1% becomes groundwater. Moreover, there is wide variation in streamflow, both seasonally and annually, with the highest annual streamflow in some large rivers exceeding the annual mean by a factor 300. The wetter areas are all confined to the coastal and mountainous parts of the continent (see Figure 1).

Australia's rivers drain a total runoff volume of about 440 km^3 to the sea annually (Yang 2015, Yang and French 2018), estimates of this vary between 343 and 465 km^3. The uneven distribution of water resources in space can be seen from the data: about ¼ of the continent contributes 88% of the runoff, it being highest in Tasmania, Northwest Queensland and part of Western Australia. Tasmania accounts for less than 1% of the area of Australia but is responsible for 14.5% of total runoff. Less than 5% of the area of the continent can boast a runoff in access of 250 mm annually. Australia's water resources are highly variable (see Table 2), and this reflects the drastic variation of climatic conditions and terrain, and it is difficult for industry to use. In addition, the level of development of Australia's water resources ranges from heavily regulated rivers and ground-water resources to rivers and aquifers in almost pristine condition. Most large urban cities and dams are situated in the southern regions of Australia with industry and irrigated agriculture principally located in the Murray Darling Basin where only 6.1% of the national surface water resources reside. Therefore, while Australia has

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significant water resources, the populations and agricultural activities are concentrated where water resources are most limited (Table 1).

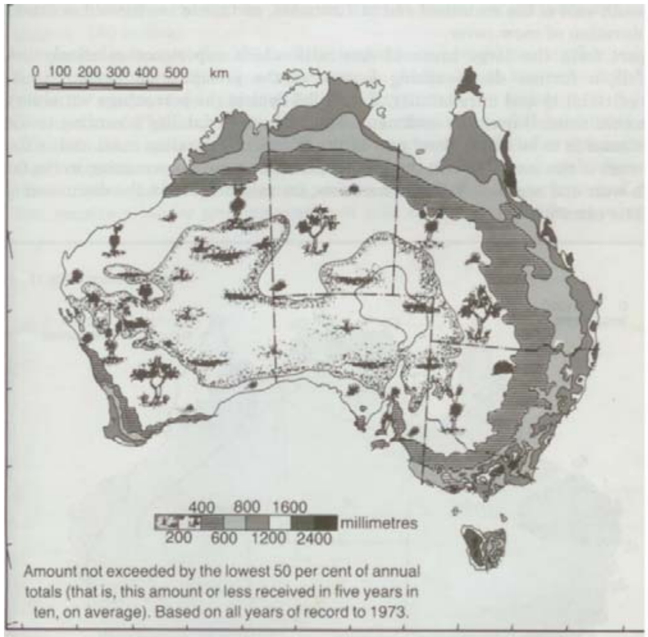

Figure 1: Australia long-term average annual rainfall

Currently, Australians extract about1 70-80 km^3/year of water and only about 18-25 km^3/year of water is used, with the remainder returned back to the environment after being used for applications such as hydropower. Table 3 shows that more than 75% of used water is related to irrigated agriculture.

Table 2: comparison of river flows between Australia and others

Country	River	Ratio between the maximum and the minimum annual flows
Switzerland	Rhine	1.9
China	Yangtze	2.0
Sudan	White Nile	2.4
USA	Potomac	3.9
South Africa	Orange	16.9
Australia	Murray	15.5
Australia	Hunter	54.3

The first National Survey of Water Use in Australia was published in 1981, and reveals that the country's annual water use was 17.8 km^3, or 3500 litres per person daily. Some 74% is used for irrigation with a further 8% used for other rural purposes. The remaining 18% of water is used for urban and industrial purposes. Australia has one of the highest per capita consumptions of water in the world.

Of all the water consumed as shown in Table 3, 85% comes from surface water sources, the Murray and Darling Rivers provide almost ¾ of all water used. However, in different parts of Australia, the exploitable proportion of the runoff depends on local factors. In the northern rivers, because of their dramatic change in flow-rates, only about 20% of the runoff is available. In the Murray and Darling River, the proportion available for use is estimated at 83%. Over the entire continent, the average exploitation of runoff is about 13%, a figure that seems to suggest that Australia's water resources are poorly utilised. However, most of the available water supplies are so far from population centres that they are uneconomic to use---highlighting the problem of uneven distribution of people and water supplies in this country and the development cost required for their use is far too expensive.

Australia is blessed as a country with abundant mineral resources. Australia earned $202 billion or 10.4% of GDP from mining while agriculture contributed 3% (about $50 billion) to GDP in 2019. Australia is number 10 in the list of countries with natural resources, comparable with USA. Australia has large reserves of coal, copper, iron ore, nickel, oil shale, and other rare metals. The country has the world’s largest gold reserves, supplying over 14% of the world's gold demand and also 46% of the world's uranium demand. Australia is the top producer of iron ore, lead, rutile, tantalum, uranium, zinc and Zircon. Australia was in the world’s top four exporters of black coal and sixth for brown coal in 2018. Mining in Australia has long been a significant industry and a major contributor to the Australian economy in relation to export income and employment. Historically, mining booms have also led to population growth via immigration to Australia, e.g., the Australian gold rushes in the 1850s produced 40% of the world's gold at that time. Many different ores, gems and minerals have been mined in the past and a wide variety are still mined throughout the country.

Table 3: Comparison of Annual water availability/used in Australia between 2000-2001 and 2018-2019 in GL.

	2000-2001	2018-2019
Mean annual rainfall		3,200,000 (352 mm/yr)
Mean annual runoff	387,184	
Total water consumed	24,908	76,000
Agriculture	16,660	
Forest & fishing	27	
Mining	401	
Manufacturing	866	
Electricity & gas	1,688	51,300
Water supply, sewer & drainage	1,794	
Household water	2,182	1,810
others	3,973	

Australia has mining activity in all of its states and territories as shown in Figure 3. The Minerals Council of Australia estimates that 2000 km^2 of Australia's land surface is directly impacted by mining and its distribution can be roughly seen from these maps, the important areas include the Goldfields, Peel and Pilbara regions of Western Australia, the Hunter Region in New South Wales, the Bowen Basin in Queensland, the Latrobe Valley in Victoria and the Murray-Darling basin. Places such as Kalgoorlie, Mount Isa, Mount Morgan, Broken Hill and Coober Pedy are known as mining towns. The major mining activities in 2018 are listed below:

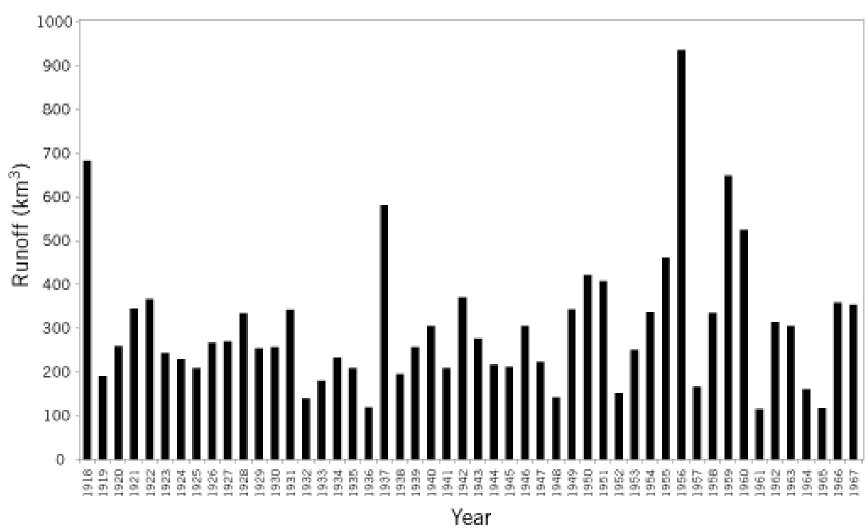

Figure 2: Annual runoff from Australian Rivers

Olympic Dam in South Australia produced 6% of the world’s copper, silver and uranium, the world's largest uranium resource. The Super Pit gold mine in Western Australia has replaced a number of underground mines at Boulder.

Australia is the world's largest exporter of coal and fourth largest producer of coal after China, USA and India. Coal is mined in every state of Australia except South Australia, and generally the coal mines are located in the coastal areas. 54% of the coal mined in Australia is exported, mostly to eastern Asia. Coal provides for about 85% of Australia's electricity production. In total, industrial water use including mining and manufacturing utilizes about 20% of all water consumed in Australia. Some cities and manufacturers need high-quality water, sometimes even better than the quality of drinking water, e.g. the cooling water for steel makers. The required salinity is only 50 ppm, lower than drinking water's 250 ppm. Among all industrial water users, mining is a large user and this use is growing fast. Generally, the mining industry uses water in remote areas where it is often dry with low rainfall and runoff. This paper discusses how to supply sufficient, high-quality and affordable water to meet industrial needs. It is proposed that coastal reservoirs will harvest river runoff and store it in the sea to meet the coastal city's water demand. The existing dams that currently supply water to these coastal cities can be used for the mining industry. The objective of this paper is to examine this proposal's feasibility.

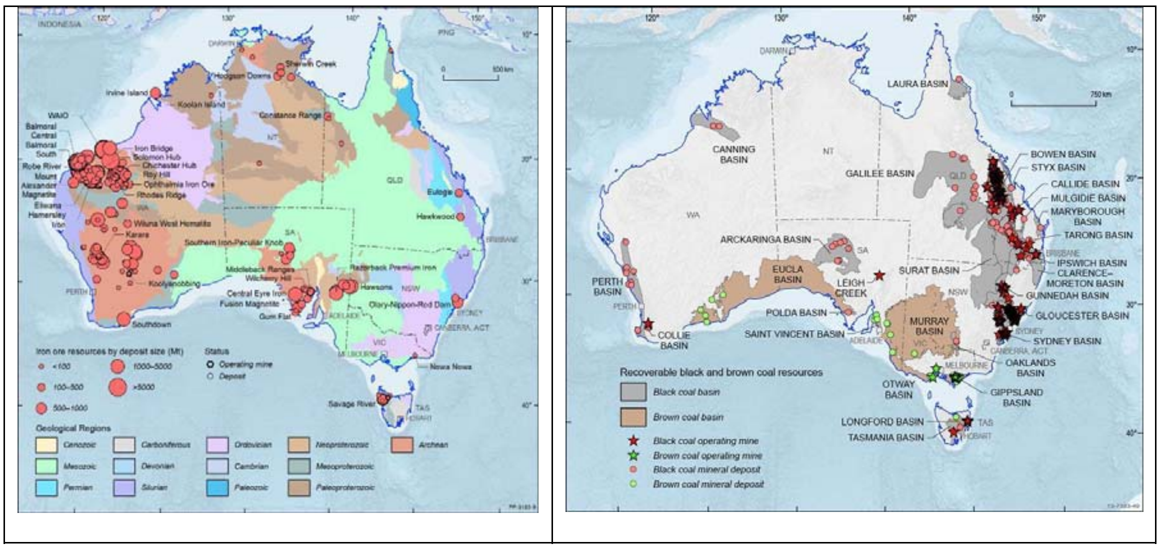

Figure 3: Australia iron ore and coal mining industry

COASTAL RESERVOIR TECHNOLOGY AND DOWNSTREAM WATER MANAGEMENT?

A coastal reservoirs is defined as a small water storage inside a large water body, separated by a barrier or barriers with some specific purpose, for instance irrigation, flood control, water supply, seawater intrusion control, and so on. (Yang and Kelly, 2015; Yang et al., 2013). As shown in Figure 4, the water inside the reservoir is different from the outside seawater in terms of chemical, physical and biological properties such as density, salinity, turbidity, nutrients, organic matter. For freshwater supply, the coastal reservoir could be simply defined as a freshwater reservoir inside seawater, with the main difference between the inside/outside waters being salinity (Yang et al. 2005).

Before the 1960s, almost all coastal reservoirs in the world were constructed for agricultural purposes due to food shortages and to solve problems like seawater intrusion prevention, land reclamation etc. Water shortages started in the 1960s when people began to migrate to coastal cities. Hong Kong was the first city in the world to experience water shortage problems caused by rapid urbanization, and the effective solution was to construct the Plover Cove coastal reservoir, where sea space is used to store rainwater. This large scale CR ended Hong Kong's water shortage; this is also the world earliest modern coastal reservoir for a city's water supply. Plover Cove's construction work was completed in 1968. Its storage capacity was about 170 GL. In 1970, its 2 km long dam was increased to 28 m high, and its capacity increased to 230 GL (see Fig. 5). As mainland China has agreed to supply water to Hong Kong, this coastal reservoir is now used as a backup water source. However, Hong Kong's experience demonstrates that it is technically feasible to store fresh water in sea space.

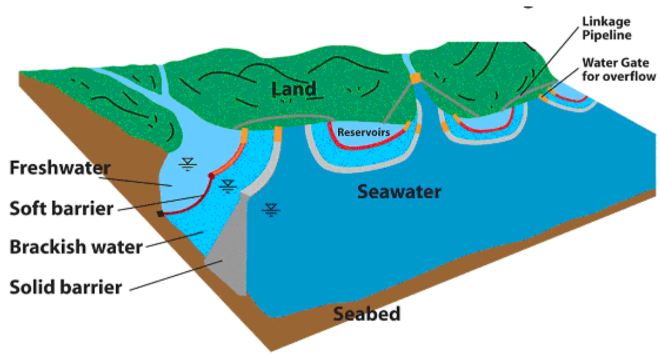

Figure 4: Conceptual coastal reservoirs to develop river flows otherwise lost to the sea

Shanghai is one of the world's largest cities with a population of 24 million in 2019, situated to the south of the Yangtze River mouth. The Yangtze River is the third-longest river in the world. Shanghai is notorious for the water crisis caused by pollution from its mother river, the Huangpu. This river has been heavily polluted and International communities have long foreseen Shanghai's water crisis. For example, in 1996 a conference organized by the UN Centre for Human Settlements (UN-Habitat) predicted that Shanghai would be one of a dozen cities with the most severe water crisis worldwide (N'Dow 1996) in the 21st century. The Shanghai Urban Master Plan in 2005 also predicted that the freshwater shortage in the city would reach 6 million m^3/d by 2020 (Lin et al., 2018). Surprisingly, the original idea to solve this megacity's water problem comes from a near failed industrial project.

MINING INDUSTRY'S WATER DEMAND AND SOLUTION

Australia is a dry nation. In 2008–09, manufacturing, mining, food processing, electricity, gas supply and other industries consumed 2840 GL of water, which is about 20% of the total Australian water consumption for that year. Amongst the usage, 508 GL was used for the mining industry, compared to 582 GL of water in 1993-1994. In 2014-2015, Australia consumed over 17,000 GL of water across all sectors, and the mining industry used over 700 GL/year of water. In 2020 about 810GL-940 GL/year of water used by the mining industry is expected. It is believed that there is strong further growth for mining water as iron ore extraction and the coal seam gas industry start to bloom with exponential growth in coming decades.

There has been exponential growth in the production from most Australian mining industries, from metals to coal products since the 1950s. Coal production reached its highest level of approximately 815 Mt/year in 2008 up from 456 Mt/year in 1994. Iron ore has also grown from 129 Mt/year in 1944 to approximately 340 Mt/year in 2008. Increasing production requires large volumes of water to be used. The increasing production of coal and iron ore makes continuing access to water a critical imperative for the industry.

Different from agriculture, industry uses a very small fraction of water, but it tends to have very high economic return in dollars. Even so, Australia industry water demand is generally difficult to meet, especially for industries in the Hunter Valley or Murray-Darling River basin where few new water licences are available for industry to purchase. After the failure the of Murray-Darling Basin plan in 2019, the total licensed extraction has been actually reduced for irrigation and industry. The high-security water entitlements that industry requires are infrequently traded, almost impossible to obtain from the water market. Alternatively, the lower security entitlements were purchased to meet industry needs.

As shown in Figure 3, most mining sites for coal and iron ore are located in arid or semi-arid regions where water is scarce, and agricultural water is competing with the industrial water in the Murray-Darling basin, and domestic water is also competing with the mining industry in West Australia. The mining industry in northern Australia and southern Australia is less competative due to lower population and less agriculture. Groundwater is used in South Australia, northern Australia is wet. Mines in southern Australia are likely to experience lower water availability, more severe droughts, and full allocation of water to users. There is less chance of reduced water supply to mining in northern Australia under climate change (Prosser, 2011).

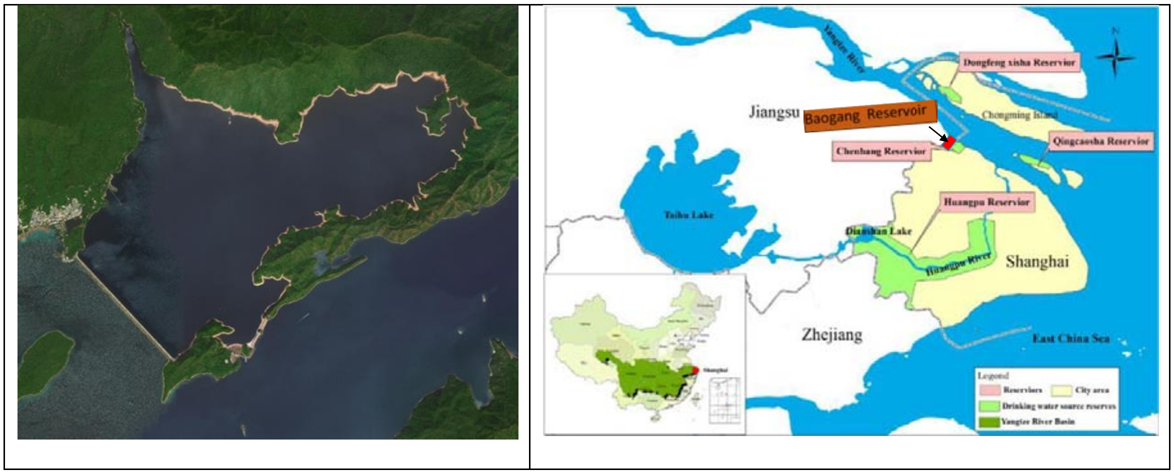

Figure 5: Coastal reservoirs in Hong Kong (left) and Shanghai (right).

SOLUTION TO MEET MINING WATER DEMAND

The following suggestions are proposed to secure the water needs for Australian industry and mining: Coastal cities' drinking water and industrial water are supplied from coastal reservoirs.

The Murray-Darling basin's agriculture, especially the Darling River's cotton farms are relocated to the river mouth and the coastal reservoir, i.e., Lake Alexandrina supplies the water for these farms. All existing dams that currently supply water to cities/agriculture should supply water to meet the nearby demand from towns, industry and mining industry. For those far away from dams/coastal reservoirs, the trains that deliver ore/coal to a port can be used to transport freshwater from the port's coastal reservoir to the inland sites where water is needed.

The feasibility of the above strategy is investigated as follows:

In general, people like to live near the coast because of a better aesthetically pleasing living environment, access to a variety of recreational activities and more job opportunities. Consequently, 90% of Australia's population live within 50 km of the coast, and almost all capital cities (except Canberra) are situated by the shore. As mentioned, Australia, every year uses about 20 km^3/year of water, only 4.5% of its runoff lost to the sea. Coastal reservoirs can supply sufficient water to meet the domestic, industrial and agricultural water demand from the coastal zones. Also, the water quality can meet the industrial requirements for electricity power plants, steel makers and mining engineering.

One of interesting examples from the 1980s occurred in Shanghai when China started its reforms and the opening-up policy for its economic development. The central government decided to build the world's largest steel plant, the Baogang plant. Initially, the builders did not carefully check the Japanese design documents relating to the quality of cooling water. During the final stage of construction, the builders found that the specified salinity of the cooling water would need to be lower than 50 ppm, and much lower than tap water's salinity, 250 ppm. The Yangtze estuary's average salinity is much higher than this 50 ppm criterion. This problem could have potentially led to failure of this substantial investment. One of the steel engineers suggested the building of a coastal reservoir in the Yangtze estuary. He suggested that the intake gates of the reservoir will be open to take the river water during the lowest salinity period, but be closed when salinity is higher than 50 ppm. In 1985, the Baogang Reservoir was built, which has ensured the high quality of iron/steel products from this plant. Therefore, it is certain that coastal reservoirs in Australia can also supply sufficient high-quality water with salinity <50 ppm to manufactures for steel making or other purposes.

After analysing Australia rainfall and runoff data, it is concluded that Australia only uses about 20 km^3/year of water in total for its domestic, agricultural and industrial purposes, only 4.5% of its runoff to the sea. Australia is not running out of water, but water is running out of our river mouth during flood periods. By developing the runoff lost to the sea using coastal reservoirs, we can supply sufficient, high quality and affordable water to meet the water demands for coastal areas. Therefore, all the existing dams shown in Figure 6 can be used by inland or highland industry or agriculture.

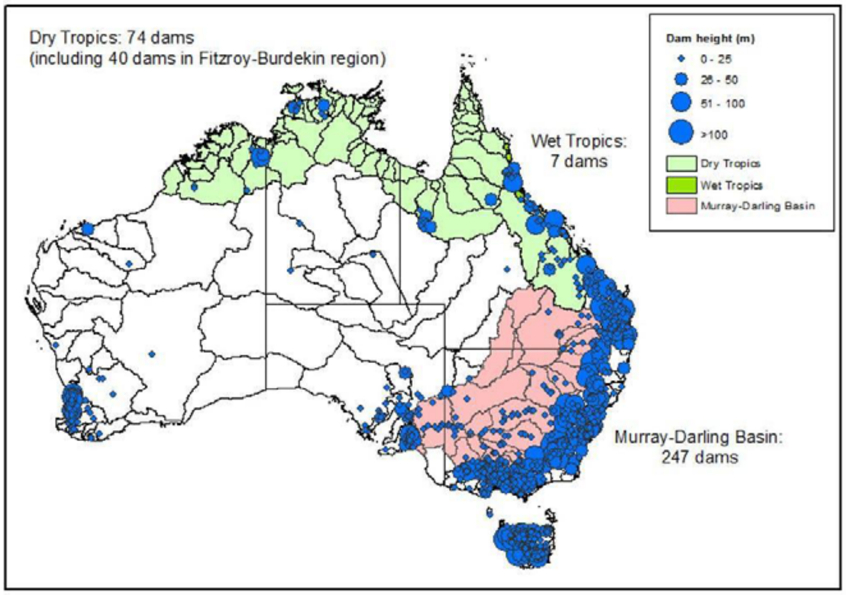

Figure 6: Existing dams that can be used for mining industry

Can we transfer water from the dams to meet mining industrial needs? The Goldfields Water Supply Scheme or the Goldfields Pipeline is a successful example implemented in Australia. It is probably the longest water supply pipeline in the world, in total it carries water over 530km from Perth to Kalgoorlie driven by eight pumping stations. The water is raised up by 411.5 m in elevation over the Darling Scarp ridge. This scheme is also probably the oldest project of a scale built over such a long distance. During the gold rush period, a 0.76 m diameter pipeline was constructed in 1903 with a capacity of 23,000 m^3/day. Until 2015, this pipeline continued to supply water to more than 100,000 people, mines, farms and other businesses in the inland region of West Australia. It generates billions of dollars of annual economic return. In 2009, the American Society of Civil Engineers listed the scheme as an international Historic Civil Engineering Landmark. On 23 June 2011, Australia added the scheme to its National Heritage List. Obviously, this is a model for other places, and the dams in Figure 6 can nourish Australia inland regions, especially for its mining industry.

Currently it is almost impossible to increase water for mining and industry in the Murray-Darling basin as it has only 6% of the country's water resources, but it produces about 2/3 of Australia's food and fibre. In 2007, the Federal Government decided to form a special department called the Murray-Darling Basin Authority (MDBA) to find a win-win solution for environment and agriculture. In 2012, the Murray-Darling Basin Plan (MDBP) became a legal document and put into effect. The core of the plan is to cap the used water, called Sustainable Diversion Limit (SDL) which determines how much water, on average, can be used by towns, communities, farmers and industries. Its target is that, by 2019, an additional 2750 GL/year of water is returned back to the river system. Its purpose is to ensure a healthy working basin faced with climate change. In 2019-2020, the abolition of the MDBP means that a new plan should be proposed, and the author has suggested the downstream water management, i.e., to relocate all cotton farms to the downstream area near the river mouth where a coastal reservoir is located (see Figure 7).

Australia is a flat country, the seawater driven by a 1m high tide and density difference can propagate upstream some 250 km in dry years from the river mouth. In order to protect farmers' crops, 5 barrages was installed at the lower lakes' outlets in 1930s, and Lake Alexandrina and Lake Albert become Australia's first coastal reservoirs. In 1960s, cotton farmers from California, USA were forced to close their business as the water was needed for drinking water. After accepted compensation, some of these farmers moved to the Murray-Darling basin. The first step was to construct dams for their irrigation as shown in Figure 7. If downstream water management was used from the 1960s, i.e., these farmers were invited to settle around the reservoirs and if they used these coastal reservoir, today we should have had no water crisis in the basin. We can let 100% of river flow run to the lower lakes first for environmental purpose first, then the water is reused for agricultural purpose, finally the worst quality after many times' reuse is discharged into the sea. Unfortunately today only 20 GL/year of the lake water is used, almost no agricultural activities are using the freshwater source.

Once the new MDBP is adopted, the existing dams in Figure 7a can be used for industrial and drinking purpose. Therefore, the agricultural output in the basin is increased, more than 2750 GL/yr of water is returned back to the river system, and also the industrial/drinking water is secured. We will have no difficulty to meet the mining industry's water demand.

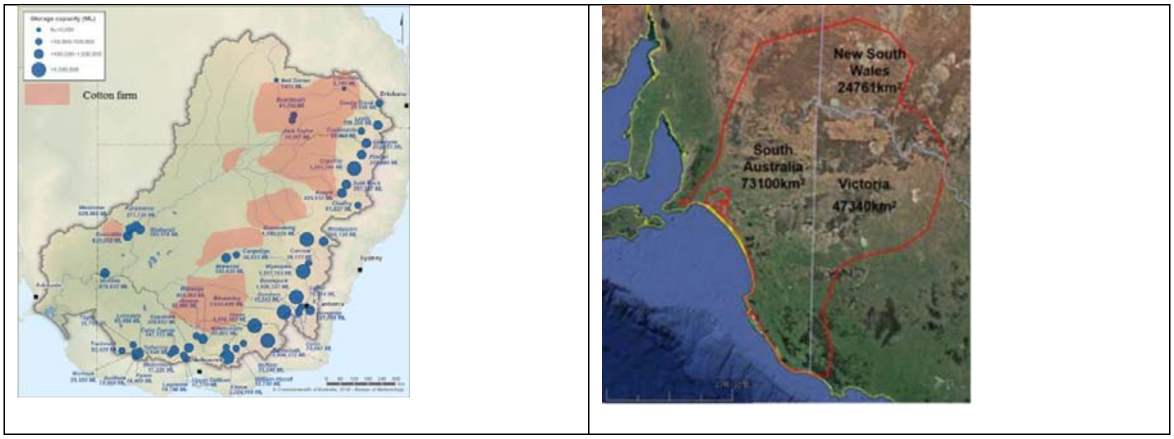

Figure 7: Dams and cotton farms' distribution in the Murray-Darling Basin (left). It is suggested to relocate all cotton farms in the left to the area enclosed by red line, thus the dam water can be used for industry and drinking purpose.

Similarly, the for Hunter River basin, a coastal reservoir can be constructed at the mouth of the Hunter River to provide the water supply for coastal regions. Once Newcastle and the central coast's water supply needs are met, the existing dams can be used for mining purposes. Grahamstown Dam and Chichester Dam in this region are large enough for coal mining operations.

Once coastal reservoirs are constructed along the coastline, coal and ore ports will have abundant supplies of water and trains that unload the ore/coal to the ports can be used to transport water bags from these ports back to the places where the water is needed. Australia has constructed a total of 36,064 km rail and for any new ore/coal development, new railways will be the 1st pre-requisite, all can be used for water bag transport in a cost effective and environment-friendly way.

CONCLUSIONS

Australia is a great and resourceful country, and also the driest inhabited continent in the world. Water scarcity has affected the country's industry activities. The country's data reveals that Australia is not running out of water, but water is running out of Australia's rivers. Every year about 440 km^3/year of runoff is lost to the sea, and the total water usage is only about 5-6% of its water availability. If coastal reservoirs are constructed at its river mouths, the coastal water demand from domestic, industrial and agricultural sites can be fully met. More than that, the inland water demand from industry can be also met as the existing dams can be diverted from supplying water to coastal cities to inland regions. The follow conclusions can be drawn from this paper: Once coastal reservoirs are constructed, all industrial water from coastal areas can be supplied from coastal reservoirs, even the high-quality cooling water used by steel makers.

To supply sufficient water to the inland areas, the author has suggested that the Murray-Darling basin's cotton farms should be relocated to downstream area near its coastal reservoirs, thus the agricultural water is fully met and also environmental flow is increased significantly. Similarly, if Newcastle's water supply comes from its coastal reservoir, Hunter River's dams can supply water for its coal mining. Generally, all existing dams can be used for the mining industry in inland areas. Water pipelines may be needed to pump water from these dams to the mining sites, trains can also transport water bags from ports to inland areas.

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